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WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts 02543 U.S.A.

Ralph A. Stephen
Senior Scientist
Department of Geology
and Geophysics
Clark 278

Telephone: (508) 457-2000, x2583
Internet: rstephen@whoi.edu
Fax: (508) 457-2150

23 October, 1995

Dr. Jeff Simmen
Program Manager
ONR Code 321OA
Ballston Tower One
800 N. Quincy Street
Arlington, VA 22217 - 5660

19960722 003

Dear Jeff:

This is my final letter for Grant No: N00014-90-J-1493. Prior to September 26, 1991 the grant was called "Three dimensional, finite-difference modeling to determine the dominant backscatter from seafloor topography and bottom heterogeneity" and Dan Burns was Principal Investigator. After that date it was called "Acoustic reverberation" and I was Principal Investigator. The period of this grant was from 01 December, 1989 to 31 August, 1995. Total amount of the grant was \$615,525. The grant was initiated by Marshall Orr in ONR Code 1125AO. The purpose of this grant was to apply our finite difference synthetic seismogram codes to low grazing angle backscatter problems. Research was carried out in accordance with the following Grantee proposals:

Date	Proposal Number	Amount
18 Oct. 89	6104.1	\$ 174,351*
26 Sept. 91	GG1284 (Revised budget and work statement for balance of the funds after Dan Burns left - \$122,500.)*	
20 Nov. 91	7200.09R	\$ 193, 174
12 Mar. 92	7619	\$ 100,000
22 Dec. 92	7800.28R2	\$ 70,000
20 Dec. 93	8400.13R2	\$ 78,000
Total		\$615,525

(* - There was some confusion in the transfer of money and responsibilities when Dan Burns left. I clarified this in a letter to Mohsen Badiy dated 20 November, 1992.)

Specific objectives of the research were: i) to add intrinsic attenuation to our Numerical Scattering Chamber (NSC) code ii) to participate in ASA and NOARL sponsored benchmark studies for range dependent media, iii) to apply the NSC to scattering from canonical models to identify the physical mechanisms responsible for low angle back scatter, iv) to address the issue of stochastic versus deterministic methodologies for seafloor scattering v) to combine finite differences with ray theory in a hybrid scheme, vi) three dimensional finite difference modeling of

facets, sediment cover, volume heterogeneities, Goff-Jordan seafloors, and ARSRP bright spot areas, and vii) to explain the relationship between deterministic features observed in the ARSRP '93 Acoustics Experiment and the geological structure of the seafloor. In addressing the last objective we chose to focus on the match filtered beam data for the wide band LFM 5sec chirps (200-255Hz). We studied initially the 1/2CZ data at Site A.

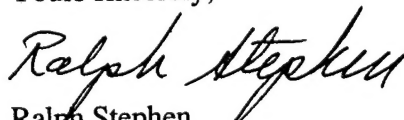
Between October 1989 and about May 1991, Dan Burns was sole PI on this grant. He delivered one paper (Burns, 1992) and two abstracts on three dimensional finite difference modeling (see below for a list of abstracts). On January 1, 1992 I became PI on 90-J-1493. In the area of two dimensional modeling we delivered four papers (Stephen, 1993; Stephen, submitted; Stephen and Swift, 1994; Swift and Stephen, 1994), four technical reports (Caruthers et al., 1994; Little and Stephen, 1995; Stephen, in press; Swift et al., 1995), and 17 abstracts. Also included in Grant 90-J-1493 were funds to continue the three dimensional modeling without Dan. After Dan left we generated one paper (Bradley and Stephen, submitted), one thesis (Bradley, 1994) and 3 abstracts on three dimensional modeling. I participated in the 1993 Acoustics Cruise (Scientific Party, 1993). Also we analyzed ARSRP acoustics data and its relationship to seafloor properties without direct finite difference modeling. We have generated one paper (Greaves et al., submitted), one thesis (Li, 1995) and three abstracts on this ARSRP data analysis.

Early work on the Acoustic Reverberation SRP was funded under N00014-90-J-1541 and the final report for this grant was mailed to you on 7 March, 1995. The work on the ARSRP is being continued under Grant N00014-95-I-0506 and an ASSERT Grant N00014-93-I-1352.

A number of the above talks included videos (2-D and 3-D). In addition to the above materials I have prepared planning letters, forwarded to ONR annual progress reports, submitted view graphs and videos for upper level ONR presentations and presented proposals at the annual ONR Site Reviews.

My group enjoys working on the ARSRP very much and we look forward to future work which will involve more real data. I believe that we have sent or given you copies of all of the material listed below, however if you need extra copies please let me know. We appreciate your support. Thanks.

Yours sincerely,


Ralph Stephen

cc: Roy Smith, WHOI

Refereed papers under Grant N00014-90-J-1493

- Bradley, C.R., and Stephen, R.A. (**submitted**). "Modeling of seafloor wave propagation and acoustic scattering in 3-D heterogeneous media," J. Acoust. Soc. Am.
- Burns, D.R. (**1992**). "Acoustic and elastic scattering from seamounts in three-dimensions - a numerical modelling study," J. Acoust. Soc. Am. **92**, 2,784-2,791.
- Greaves, R.J., Stephen, R.A., and Caruthers, J.W. (**submitted**). "Seafloor acoustic backscattering from different geological provinces in the Atlantic Natural Laboratory," J. Acoust. Soc. Am.
- Stephen, R.A. (**1993**). "A numerical scattering chamber for studying reverberation in the seafloor," in *Ocean reverberation*, edited by D.D. Ellis, J.R. Preston, and H.G. Urban (Kluwer, Dordrecht), pp. 227-232.
- Stephen, R.A. (**submitted**). "Modeling sea surface scattering by the finite difference method," J. Acoust. Soc. Am.
- Stephen, R.A., and Swift, S.A. (**1994**). "Modeling seafloor geoacoustic interaction with a numerical scattering chamber," J. Acoust. Soc. Am. **96**, 973-990.
- Swift, S.A., and Stephen, R.A. (**1994**). "The scattering of a low-angle pulse beam by seafloor volume heterogeneities," J. Acoust. Soc. Am. **96**, 991-1001.

Technical Reports under Grant N00014-90-J-1493

- Caruthers, J.W., Fricke, R., and Stephen, R. (**1994**). "Acoustic reverberation at selected sites in the mid-Atlantic ridge region.," 1994 NRL Review, 118-123.
- Little, W.S., and Stephen, R.A., (**1995**). *AFRAME: A video animation capability for displaying FINDIF numerical model output* (WHOI-02-95), Woods Hole Oceanographic Institution.
- Scientific Party (**1993**). *ARSRP - Initial report - Acoustics Experiment - R/V Cory Chouest- 5-26 July, 1993* Office of Naval Research, Washington, D.C.
- Stephen, R.A. (**in press**). Modeling sea surface scattering by the finite difference method. In S. Chin-Bing (Ed.), *Reverberation and Scattering Workshop*, Bay St. Louis, Mississippi: NRL.
- Swift, S.A., Little, W.S., and Stephen, R.A., (**1995**). *Signal and noise levels in numerical scattering chamber snapshots* (WHOI-01-95), Woods Hole Oceanographic Institution.

Theses under Grant N00014-90-J-1493

- Bradley, C.R. (**1994**). *Very low frequency seismo-acoustic noise below the sea floor (0.2-10Hz)* Ph.D. Thesis, Massachusetts Institute of Technology and Woods Hole Oceanographic Institution.
- Li, L. (**1995**). *Computer modeling of a vertical array in a stratified ocean* M.Sc. Thesis, Massachusetts Institute of Technology and Woods Hole Oceanographic Institution.

Abstracts under Grant N00014-90-J-1493

Finite Difference 3D - Burns

- Burns, D.R., Three dimensional finite difference modeling of acoustic backscatter from rough seafloors. Second Annual Acoustic Reverberation SRP Scientific Meeting, Scripps Institution of Oceanography, March, 1991.
- Burns, D.R., Three dimensional finite difference modeling of acoustic backscatter from rough seafloors. Fall ASA, La Jolla, 1990, J. Acoust. Soc. Am., 88, S108.

Finite Difference 3D - Stephen

- Bradley, C.R. and Stephen, R.A. Three dimensional modeling of low-angle seismoacoustic backscatter. Spring ASA, Ottawa, May 1993, J. Acoust. Soc. Am., 93, 2322.
- Stephen, R.A. and Bradley, C. Three dimensional modelling of low angle backscatter from facets. 1992 Fall Research Symposium, Bottom/subbottom Acoustic Reverberation Special Research Program, WHOI, Woods Hole, MA.
- Stephen, R.A. and Bradley, C.R. Three dimensional finite difference modeling of geoacoustic interaction at the seafloor. SIAM 1993 Annual Meeting, Philadelphia, July 1993 (Invited Lecture).

Numerical Scattering Chamber 2D

- Ellis, D.D., Kampanis, N. and Stephen, R.A. Calculations of ocean bottom and sub-bottom backscattering using a time-domain finite-difference code. NATO Symposium on Ocean Reverberation, La Spezia, Italy, May 25-29, 1992.
- Stephen, R.A. A numerical scattering chamber for studying reverberation in the seafloor. NATO Symposium on Ocean Reverberation, La Spezia, Italy, May 25-29, 1992.
- Stephen, R.A. Quantitative backscattering coefficients from the numerical scattering chamber. 1992 Fall Research Symposium, Bottom/subbottom Acoustic Reverberation Special Research Program, WHOI, Woods Hole, MA.
- Stephen, R.A. and Swift, S.A. Two dimensional modelling of low angle backscatter from geologically realistic seafloors. 1992 Fall Research Symposium, Bottom/subbottom Acoustic Reverberation Special Research Program, WHOI, Woods Hole, MA.
- Stephen, R.A., Swift, S.A. and Bradley, C. The scattering of low grazing angle geoacoustic fields from rough seafloors. Third Annual Acoustic Reverberation SRP Scientific Meeting, Scripps Institution of Oceanography, April, 1992.
- Stephen, R.A. Intrinsic attenuation and scattering in laterally inhomogeneous sediments. Spring ASA, Salt Lake City, 1992, J. Acoust. Soc. Am., 91, 2462 (Invited Lecture).
- Stephen, R.A. Modeling acoustic propagation in shallow range dependent environments. Spring ASA, Ottawa, May 1993, J. Acoust. Soc. Am., 93, 2270.
- Stephen, R.A., Shaw, P.R. and Caruthers, J.W. Modeling deterministic features in the ARSRP acoustic data. Fourth Annual Acoustic Reverberation SRP Scientific Meeting, Scripps Institution of Oceanography, December, 1993.
- Stephen, R.A. and Swift, S.A. Quantitative backscattering coefficients from the numerical scattering chamber. Fall ASA, Denver, October 1993, J. Acoust. Soc. Am., 94, 1784.
- Stephen, R.A. and Swift, S.A. Two dimensional modeling of low-angle backscatter from geologically realistic seafloors. Fall ASA, Denver, October 1993, J. Acoust. Soc. Am., 94, 1800.

Abstracts under Grant N00014-90-J-1493, cont'd

Numerical Scattering Chamber 2D, cont'd

- Stephen, R.A., Swift, S.A. and Shaw, P.R. Modeling acoustic 'bright spots' from ARSRP Site 'A'. Fourth Annual Acoustic Reverberation SRP Scientific Meeting, Scripps Institution of Oceanography, March 1993.
- Stephen, R.A. and Swift, S.A. The numerical scattering chamber and seafloor scattering functions. Fall AGU, San Francisco, 1993, EOS, 74, 395.
- Stephen, R.A. Optimal beamwidths for seafloor scattering problems. Fall ASA, Austin TX, November 1994, J. Acoust. Soc. Am., 96, 3266.
- Stephen, R.A. and Swift, S.A. The scattering of a low-angle pulse-beam from seafloor volume heterogeneities. Fall AGU, San Francisco, 1994, EOS, 75, 579.
- Stephen, R.A. Modeling sea surface scattering with the finite difference method. Spring ASA, Washington, D.C., June 1995, J. Acoust. Soc. Am., 97, 3405.
- Stephen, R.A. and Swift, S.A. The scattering of Gaussian pulse-beams at fluid-solid interfaces. International Union of Geodesy and Geophysics XXI General Assembly, Boulder, July, 1995, B387.
- Stephen, R.A. and Swift, S.A. Seismic wave propagation and scattering in strongly heterogeneous upper oceanic crust. Fall AGU, San Francisco, December 1995.

ARSRP Data Analysis

- Caruthers, J.W., Fricke, J.R. and Stephen, R.A. Acoustic reverberation at selected sites in the Mid-Atlantic Ridge region. Fourth Annual Acoustic Reverberation SRP Scientific Meeting, Scripps Institution of Oceanography, December, 1993.
- Greaves, R.J. and Stephen, R.A. Mean intensity maps near Site A. Acoustic Reverberation SRP Scientific Meeting, MIT, June 1994.
- Greaves, R.J. and Stephen, R.A. Seafloor acoustic backscattering from different geological provinces in the Atlantic Natural Laboratory. Acoustic Reverberation SRP Scientific Meeting, Woods Hole, July 1995.
- Greaves, R.J., Stephen, R.A. and Caruthers, J.W. Seafloor acoustic backscattering from different geological provinces in the Atlantic Natural Laboratory. Fall AGU, San Francisco, December 1995.
- Shaw, P.R., Smith, D.K., Stephen, R.A. and Caruthers, J.W. Multiscale, multisensor analysis of seafloor topography in the ONR Atlantic natural laboratory. Fourth Annual Acoustic Reverberation SRP Scientific Meeting, Scripps Institution of Oceanography, December, 1993.
- Stephen, R.A., Shaw, P.R., Greaves, R.J., and Caruthers, J.W. Modeling deterministic features in the ARSRP data. Spring ASA, Cambridge, MA, June 1994, J. Acoust. Soc. Am., 95, 2826.
- Stephen, R.A. and Greaves, R.J. Analysis of ARSRP acoustic data in the vicinity of Site A. Acoustic Reverberation SRP Scientific Meeting, MIT, June 1994.